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Original communication

Reconstruction of femur length from its fragments in South Indian males

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A B S T R A C T

Stature is one of the essential parameters in the establishment of identity of an individual. It is well documented from the previous studies that intact femur has the highest correlation with stature and as such widely used in the regression equation derivations. However, the femur is not always recovered intact in forensic cases, thereby rendering the equations derived from the whole bone inappropriate for analysis. This has necessitated the derivation of regression equations for estimating the length of femur, from the fragments of femur. The calculated maximum femoral length can then be used to estimate the stature of the individual by the regression equations, tables or the multiplication factors already established by the various studies.

Seven variables were measured in a sample of 60 male femora. All the measurements showed positive degree of correlation. Regression equations for the estimation of maximum length of femur were derived. It is therefore stated that in the absence of intact femur, regression equations derived from the present study can provide a reliable estimate of maximum length of femur in South Indian males and thereby the adult stature.

1. Introduction

Identification is the recognition of an individual by means of various physical features and biological parameters, which are unique to each individual. There are various established parameters for identification of an individual. Different traits of human beings develop differently. Skeletal development is influenced by a number of factors such as nutrition, environment, hormones, etc. Due to differences in skeletal proportions in different geographical areas, it is desirable to have some means of giving quantitative expression to variations of such traits.

The question of identification arises in everyday medicolegal practice, in civil and criminal cases. The identity of a dead body may be destroyed by animals, exhumed fragmented bodies, mass disasters such as Mangalore plane crash[1] and deliberate mutilation of dead bodies as in Nithari serial murder, Noida.[2]

Thus in many conditions forensic investigators have an uphill task to analyse whatever skeletal remains are found and draw inferences of about their identity.

Proper analysis of the skeletal remains includes determination of the species, races, sex and the stature of the individual as well as the possible cause of death and time since death.[3–6]

Determination of some of these parameters requires the presence of one or more complete long bones, a condition that frequently eludes the investigator. From the previous researches, it was established that the stature could be estimated with long bones either by using multiplication factor or with the application of regression formulae,[7] but the easiest and the reliable method is by regression analysis.[8,9]

In the past, scientists have used each and every bone of the human skeleton right from femur to metacarpals in estimation of stature. They all have reached a common conclusion that stature can be estimated with great accuracy even from the smallest bone, although they have encountered a small error of estimate in their studies.

From the results of all previous studies, the femur in the intact state is one of the bones with highest correlation with stature. It has also been shown to yield the best accuracy in the estimation of stature for any individual skeletal element. However, the femur is not always recovered intact in forensic cases, thereby rendering the equations derived from the whole bone inappropriate for analysis. This has necessitated the derivation of regression equations for estimating the length of femur, from the fragments of femur. Since the regression equations are population specific, it was the aim of this study to derive regression equations from such fragments in South Indian male population.

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In the present study, the length of the femur was assessed anthropometrically in relation to the various fragments of femur. This study is an effort to derive regression equations for the reconstruction of the length of the femur from its fragmentary remains, based on its metric evaluation.

2. Materials and methods

2.1. Materials

As many as 60 adult femora for the study were collected from unidentified, unclaimed male bodies coming for routine medico-legal postmortem examination to the Institute of Forensic Medicine, Chennai, during the period from 1 August 2008 to 31 July 2010.

From all the corpses, femora were removed by giving lateral skin incision in the thigh extending from hip joint to knee joint. The knee was flexed and the quadriceps tendon, the joint capsule and the cruciate ligaments were incised. The muscular attachments were dissected, and by flexing and rotating the femur, the capsule of the hip joint and other ligaments were incised. The soft tissues were removed by treating the femur with antiformalin solution. Bones with any injury, deformity or artefact were discarded.

2.2. Methods

The maximum length of femur was measured by osteometric board and the other following measurements were taken using electronic digital vernier sliding caliper.

Definition of fragments:

Fragment	Description
FML – maximum length of femur	Linear distance between the most superior part of the head of the femur and the most inferior part of the medial condyle.
VHD – vertical diameter of the femoral head	Linear distance between the highest and lowest points of the head in the equatorial plane
VHA – upper breadth of femur	Linear measurement between the most superior point on the fovea capitis to the inferior aspect of the greater trochanter
VND – vertical neck diameter	Minimum linear distance between the superior and inferior points on the neck of the femur
FDL – epicondylar breadth	Linear distance between the most projected points on the epicondyles. The measurement is taken right angle to the shaft axis.
BCB – bicondylar breadth	Most lateral and posterior projection of the lateral condyle, to the most medial and posterior projection of the medial condyle
MCL – medial condyle length	Linear distance between the most anterior and the most posterior points on the medial condyle
LCL – lateral condyle length	Linear distance on the lateral condyle measured in an anteroposterior direction

Five of the measurements, vertical diameter of the femoral head (VHD), vertical neck diameter (VND), upper breadth of femur (VHA), bicondylar breadth (BCB) and epicondylar breadth (FDL)) were used in this study because of the ease with which they could be reproduced. Because of the high coefficient of reproducibility, two other measurements, namely, medial condylar length (MCL) and lateral conylar length (LCL), were also selected.

Table 1
The descriptive statistics of the male samples.

Measurement	No.	Minimum CM	Maximum CM	Mean CM	Std. deviation
FML	60	41.2	47.8	44.9	1.5
VHD	60	4.2	5.11	4.6	0.2
VND	60	2.76	3.9	3.2	0.3
VHA	60	8.54	10.55	9.5	0.5
BCB	60	6.23	8.27	7.2	0.5
FDL	60	7.34	8.47	8.0	0.3
LCL	60	5.28	7.35	6.2	0.5
MCL	60	5.35	7.44	6.3	0.5

The data were collected and placed into excel sheets; statistical analysis was carried out using SPSS software.

Then, correlation coefficients and standard error of estimate (SEE) were obtained. As a thumb rule, we shall consider correlation coefficients between 0.00 and 0.30 as weak, those between 0.300 and 0.700 as moderate and coefficients between +0.70 and 1.00 as high.

The correlation of the femoral fragmentary measurements to the maximum length of femur was studied both individually and in combination. Correlation of the measurements of the proximal femoral fragments individually and in combination to the maximum length of femur was studied. Similarly, correlation of the measurements of the distal femoral fragments individually and in combination to the maximum length of femur was studied.

Regression equations were formulated from these coefficients. Regression equation with the maximum length of femur as dependent variable and other measurements as the independent variables were obtained using the total sample ($N = 60$). Maximum length of femur (FML) was regressed on both individual measurements and combination of measurements.

3. Results

- All the measurements showed positive degree of correlation.
- All the parameters showed a high degree of correlation, except VHD which display moderate degree of correlation.
- Among all the fragments, the distal fragments (epicondylar breadth and MCL) correlated well with the femoral length. The measurements of the distal fragments consistently showed the best correlation with FML.
- While considering the proximal end, measurement of the VHA showed better correlation (Tables 2 and 3).

The equations were obtained by linear regression analysis of the individual measurements with the FML.

- The equations regressed to determine the FML using independent variables showed moderate to lower degree correlation (Table 4). The regression equations from the individual distal FDL and MCL fragment showed the highest correlation 0.658 and 0.657 with SEE 0.888 and 0.889, respectively.
- The equations regressed to determine the FML using combined measurements of different femoral fragments showed higher degree correlation than with individual measurements (Table 5). When all the three fragmentary measurements of the proximal end were combined in regressing the equation, the equation yielded has better correlation with femoral length (0.879) (Table 6).

Likewise the equations derived from combining the measurements of the distal end of the femur (epicondylar breadth, bicondylar breadth, medial condylar length and lateral condylar length) presented a higher correlation (0.756–0.751) (Table 7).

Table 2
Correlations of measurements of fragments of femur with maximum length of femur (FML) in descending order.

Fragments	FDL	MCL	VHA	LCL	BCB	VND	VHD
FML (males)	0.811(**)	0.811(**)	0.806(**)	0.794(**)	0.770(**)	0.709(**)	0.618(**)

** Correlation is significant at the 0.01 level (2-tailed).

Table 3
p-value fragments of femur with maximum length of femur (FML).

Fragments	VHD	VND	VHA	BCB	FDL	LCL	MCL
FML (males)	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4
Regression equations that can be used to determine FML using independent variable.

Equations	Correlations	SEE
13.105 + 3.994(FDL)	0.658	0.888
30.340 + 2.303(MCL)	0.657	0.889
22.563 + 2.335(VHA)	0.649	0.900
28.611 + 2.603(LCL)	0.630	0.925
27.511 + 2.398(BCB)	0.593	0.970
34.302 + 3.255(VND)	0.503	1.072
25.606 + 4.187(VHD)	0.382	1.195

4. Discussion

Stature has been estimated in different population groups by deriving regression equations using the intact long bones of the upper and lower extremities. Various efforts have been made in the estimation of stature from the different elements of the human skeleton since the 19th century when Pearson first derived regression equations for stature estimation.[8] Estimation of stature requires the presence of one or more long bones, a condition too often uncommon as cited in the introduction. So to overcome this hurdle is to estimate the total length of the long bone from the fragments and later employ them in statural formulae to get reasonably accurate stature.[10–12] This necessitates the need to assess the usefulness of measurements of fragments of long bones (e.g., femur).

Many researches had been done in the past to estimate the length of femur and subsequently the stature, using the bone fragments like Chandra et al.,[10] Steele and McKern,[11] V R Mysorekar et al.[12] and Shroff AG et al.[13] However, over a period of time when these data were actually put in practice, forensic anthropologists faced difficulties in locating precise anatomical landmarks in the fragmentary remains, as reported by Simmons et al.[17]

As a result, Simmons et al. used eight standard measurements of the femur in the estimation of maximum femoral length of Americans.[14] Four of their measurements (VND, UEpl, BCB and EpB) and two other measurements of the distal fragment (MCL and LCL) were used by MA Bidmos to calculate the stature and maximum femoral length in indigenous South African population[15] and South African population of European Descent.[16]

Table 6
Regression equations to determine FML, using only the proximal segments of the femur.

Equations	Correlation	SEE
25.622 − 0.796(VHD) + 1.393(VND) + 1.925(VHA)	0.879	0.878
23.969 + 1.086(VND) + 1.819(VHA)	0.673	0.876

Table 7
Regression equations to determine FML, using only the measurements of the distal end of the femur.

Equations for males	Correlation	SEE
19.526 + 0.596(BCB) + 1.566(FDL) + 0.928(LCL) + 0.441(MCL)	0.756	0.771
18.013 + 0.659(BCB) + 1.865(FDL) + 1.162(LCL)	0.751	0.771

Table 8
Comparisons of the descriptive statistics of present study and Simmons study.

Study	VHD		VND		VHA		BCB		FDL	
	X	SD	*X*	SD	*X*	SD	*X*	SD	*X*	SD
Simmons white males	4.83	0.32	3.31	0.30	9.91	0.59	7.78	0.43	8.34	0.45
Simmons black males	4.76	0.27	3.11	0.26	9.90	0.58	7.77	0.46	8.3	0.42
Present study males	4.6	0.2	3.2	0.3	9.5	0.5	7.2	0.5	8.0	0.3

X − Mean; SD − Standard deviation.

In the present study, seven variables (VHD, VND, VHA, BCB, FDL, MCL and LCL) were selected and measured from 60 adult male femora and analysed.

In the study, the maximum length of femur ranged from 41.2 cm to 47.8 cm, with mean of 44.9 cm (Table 1). This result is also similar to the results as reported by Pearson and Bell,[8] Steele and Kern[11] and Schroff et al.[13]

While comparing the descriptive statistics of our study with that of Simmons et al. and Bidmos, the mean value of our samples was lower than the corresponding samples in general.[14–16] This reveals that people from Indian origin are shorter than the population sample considered by them (Tables 8 and 9).

The mean values of BCB and VHD were lower than the values as reported in previous studies by Pearson and Bell (1917–1919).[8] This is probably due to the geographic differences in skeletal development.

Correlation is a measure of association between two variables.[17] In this study, it is the strength of association between the maximum femoral length and its fragments. The moderate to high degree of correlations obtained in this study confirms the usefulness of fragments of femur in the estimation of maximum length of femur by deriving regression equations (Table 2). The correlation was statistically significant at 0.01 levels (two tailed).

Table 5
Regression equations to determine FML, using combined measurements of different femoral fragment.

Equations	Correlation	SEE
14.137 + 2.314(FDL) + 1.291(VHA)	0.740	0.781
16.603 + 1.607(FDL) + 0.963(VHA) + 1.007(LCL)	0.776	0.732
18.193 + 1.849(FDL) + 1.199(VHA) + 1.249(LCL) − 1.584(VHD)	0.796	0.704
19.977 + 1.219(FDL) + 1.228(VHA) + 1.034(LCL) − 1.933(VHD) + 0.815(BCB)	0.818	0.672

Table 9
Comparisons of the descriptive statistics of present study and Bidmos study.

Study	VND		VHA		FDL		BCB		LCL		MCL	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
SAED males	3.40	0.27	9.99	0.56	8.07	0.42	7.60	0.33	6.52	0.35	6.53	0.37
IND SA males	3.23	0.24	9.53	0.60	7.87	0.40	7.49	0.46	6.47	0.36	6.45	0.37
Males	3.2	0.3	9.5	0.5	8.0	0.3	7.2	0.5	6.2	0.5	6.3	0.5

Table 10
comparison of correlations of the present study and Simmons study.

Study		VHD	VND	VHA	BCB	FDL
Simmons et al	White males	0.526	0.384	0.606	0.541	0.521
	Black males	0.454	0.315	0.592	0.440	0.465
Present study	Males	0.618(**)	0.709(**)	0.806(**)	0.770(**)	0.811(**)

** Correlation is significant at the 0.01 level (2-tailed).

Comparing the correlation, the general trend of measurements of our study had a higher correlation with corresponding measurements of Simmons et al. and Bidmos.[14–16] In the Simmons study, the correlation rarely exceeded 0.65 and Bidmos study; it did not exceed 0.711. In the present study the FDL showed correlation of 0.811, indicating the higher predictive efficiency (Tables 10 and 11).

In our study, the distal femoral segments FDL and MCL had the best correlation to FML, contrary to the Simmons study and the Bidmos study. The proximal fragments VHD and VND are the poor predictors, as consistent with the Simmons study.

Since all the measurements in our study had positive correlation with the FML, it is prudent to derive simple linear regression ($y = a + bx$) by univariate regression analysis against the individual measurements to calculate FML from anyone of these markers. In the simple linear regression equations ($y = a + bx$), y is the FML, a is the intercept, b is the slope, and x is the measure of the predictor variable. Likewise, when a segment of femur is recovered, which may be either the proximal or distal, we can determine the maximum length of femur by the multivariate regression analysis of their respective measurements.

The measurements of the distal fragments' FDL and MCL have the superior correlation with FML in comparison to other fragments. Thus when the fragments of both femoral ends are available for the medicolegal investigation, the maximum length of femur can be best calculated from the metric evaluation of FDL or MCL fragment (Table 4) as given as follows:

$$\mathrm{FML} = 13.105 + 3.994(\mathrm{FDL}) \pm 0.888$$

$$\mathrm{FML} = 30.340 + 2.303(\mathrm{MCL}) \pm 0.889.$$

In medicolegal situations where any of the proximal femoral fragments is recovered, regression formula using the VHA measurement will prove to be more useful, as the VHD and VND have poor correlation with the maximum femoral length individually. The reliability of the calculated FML from VHA, VND and VHD is in the descending order.

In general, the regression formulae using combination of fragments indicated much better correlation with femoral length than using single fragments (Tables 5–7). Thus when all the fragments of the femoral end (proximal or distal) are submitted for medicolegal examination, FML can be predicted with considerable accuracy (Table 6). Hence in calculating the maximum length of femur, it is always advisable to combine the available fragmentary measurements for higher predictive accuracy.

The best equation to calculate the maximum length of femur using measurements of different fragments of both ends is

$$\mathrm{FML} = 19.977 + 1.219(\mathrm{FDL}) + 1.228(\mathrm{VHA}) + 1.034(\mathrm{LCL}) - 1.933(\mathrm{VHD}) + 0.815(\mathrm{BCB}) \pm 0.672.$$

The best formula to calculate FML from the proximal femoral fragments is

$$\mathrm{FML} = 25.622 - 0.796(\mathrm{VHD}) + 1.393(\mathrm{VND}) + 1.925(\mathrm{VHA}) \pm 0.878.$$

The best formula to calculate FML from the distal femoral fragments is

$$\mathrm{FML} = 19.526 + 0.596\,(\mathrm{BCB}) + 1.566\,(\mathrm{FDL}) + 0.928\,(\mathrm{LCL}) + 0.441\,(\mathrm{MCL}) \pm 0.771.$$

The calculated maximum femoral length can be used to estimate the stature of the individual by the regression equations, tables or the multiplication factors already established by the various studies. The principle can also be used to measure those dimensions in living subject after making necessary allowance for soft tissue, thereby adding on to the corpus of data on anthropometric studies in large population. The results are reliable, but further works need to be designed to get more accurate estimates in population considering the age factor as well.

One important shortcoming of the present series is that stature calculation by this approach was based on combining two separate formulae (calculating the femoral length by this formula and then estimating the stature by multiplying factor), thereby compounding the error.

5. Conclusion

Regression equations were derived for estimation of maximum femoral length from measurements of fragments of the femur. All the fragmentary measurements in our study showed positive correlations with the ML. Therefore, the maximum femoral length can be estimated from fragmentary remains of the femur. The maximum length of femur can be best calculated from the metric evaluation of FDL and MCL fragments. More authoritative equation can be obtained by analysing large size of the samples. In the absence of intact long bones, equations presented in this study can offer a reasonable estimate of maximum femoral length from which the stature can be estimated.

Table 11
Comparisons of correlations of the present study and Bidmos study.

Study		VND	VHA	FDL	BCB	LCL	MCL
Bidmos study	SAED males	0.478	0.610	0.459	0.400	0.537	0.426
	IND SA males	0.542	0.653	0.529	0.560	0.626	0.711
Present study	Males	0.709 (**)	0.806 (**)	0.811 (**)	0.770 (**)	0.794 (**)	0.811 (**)

** Correlation is significant at the 0.01 level (2-tailed).

Conflict of interest

The authors solemnly declare that there is no conflict of interest about this article.

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